(19) Japan Patent Office (JP)
(12) Publication of Unexamined Patent Application (A)
(11) Japanese Patent Laid-Open Number: Hei 4-23293
(43) Laid-Open Date: Heisei 4-1-27 (January 27, 1992)

(51) Int.Cl.4		Identification Code	Office Reference Number
G 11 C	11/14	Z	7131-5L

Request for Examination: No request to be done
Number of Inventions: 4 (13 pages in total)

(54) Title of the Invention: Magnetic Memory Cell and Magnetic Thin Film

(21) Application Number: Hei 2-126796
(22) Filed: Hei 2-5-18 (May 18, 1990)

(72) Inventor: Akihiko Tsudai
1Komukaitoushiba-cho, Saiwai-ku,
Kawasaki-shi,Kanagawa-ken, Japan
in Research Institute,
Toshiba Corporation
(72) Inventor: Youichi Toukai
1Komukaitoushiba-cho, Saiwai-ku,
Kawasaki-shi,Kanagawa-ken, Japan
in Research Institute,
Toshiba Corporation
(72) Inventor: Isamu Sakai
1Komukaitoushiba-cho, Saiwai-ku,
Kawasaki-shi,Kanagawa-ken, Japan
in Research Institute,
Toshiba Corporation
(72) Inventor: Masashi Sahashi
1Komukaitoushiba-cho, Saiwai-ku,
Kawasaki-shi,Kanagawa-ken, Japan
in Research Institute,
Toshiba Corporation
(71) Applicant: Toshiba Corporation
72 Horikawa-cho, Saiwai-ku,
Kawasaki-shi, Kanagawa-ken, Japan
(74) Agent: Patent Attorney; Takehiko Suzue (and three others)

Specification

1. Title of the Invention

Magnetic Memory Cell and Magnetic Thin Film

2. What is claimed is

(1) A magnetic memory cell comprising:

a magnetic thin film in which a magnetization easy axis has a film plane vertical direction component;

a heating circuit for locally heating the magnetic thin film; and

a reading circuit for reading out information from the magnetic thin film, the reading circuit being composed of a magnetic resistor element disposed close to the magnetic thin film so as to be capable of being coupled thereto magnetically, the magnetic resistor element changing its resistance value depending at least on application magnetic field and a transfer gate connected to the magnetic resistor element in series.

(2) A magnetic memory cell comprising:

a magnetic thin film in which a magnetization easy axis has a film plane vertical direction component;

a magnetic field generating circuit for applying local magnetic field to the magnetic thin film to change information of the magnetic thin film; and

a reading circuit for reading out the information from the magnetic thin film, the reading circuit being composed of a Hall element disposed close to the magnetic thin film so as to be magnetically coupled thereto and a transfer gate connected to the Hall element in series.

(3) A hard magnetic thin film comprising:

a memory cell element in which two magnetic bodies are tunnel-connected via an insulator layer;

a transfer gate connected to the tunnel coupling element in series; and

a magnetic field generating circuit closed to at least one magnetic body so as to be capable of being coupled magnetically thereto.

(4) A hard magnetic thin film which has M (M: one or more of Ti, Zr, and Hf) of 6 to 15 % in terms of atomic fraction, the residual portion is substantially formed one or more of Fe, Co and Ni, and a magnetization easy axis has a film plane vertical direction component.

3. Detailed Description of the Invention

[Object of the Invention]

(Field of the Invention)

The present invention relates to a magnetic memory cell and a hard magnetic thin film,

(Prior Art)

Conventionally, a magnetic disc device is a main stream of external storage devices, and a magnetic tape device, a floppy disc device and the like are also used. In recent years, an optical magnetic memory and an IC also memory come to be used.

Particularly, storage devices of a magnetic memory group has a large storage capacitance and can store a large amount of information. Moreover, because the these devices are nonvolatile, they can store data for a long time. However, since such magnetic memory uses a rotation mechanism for reading/writing of information, an access time is by far large in comparison with a semiconductor memory. Furthermore, the magnetic disc device has a problem of mechanical durability for a disc and a head starting with a problem of head crash.

On the other hand, the semiconductor memory such as DRAM has a problem that it can not store data for a long time due to its nonvolatile characteristic for example, data is lost upon turning off of power supply, and a problem that it has a considerable little memory capacitance compared with the magnetic memory.

Moreover, nowadays development of an optical magnetic memory is advanced actively, research toward practical application of an overwrite function is eagerly performed. However, a recording medium used for this optical magnetic memory is an amorphous thin film made of rare earth element and transition metal, and the recording medium has a problem in terms of corrosion resistant property due to existence of the rare earth metal.

(Subjects to be Solved by the Invention)

The present invention was made to solve the above described problems, and an object of the present invention is to provide a solid state magnetic memory cell which realizes high speed writing and erasing of data and high speed access, and can store data for a long time, and to provide a hard magnetic thin film excellent in corrosion resistance property.

[Constitution of the Invention]

A first magnetic memory cell of the present invention comprises: a

magnetic thin film in which a magnetization easy axis has a film plane vertical direction component; a heating circuit for locally heating the magnetic thin film; and a reading circuit for reading out information from the magnetic thin film, the reading circuit being composed of a magnetic resistor element disposed close to the magnetic thin film so as to be capable of being coupled thereto magnetically, the magnetic resistor element changing its resistance value depending at least on application magnetic field and a transfer gate connected to the magnetic resistor element in series.

As apparent from the constitution of the first magnetic memory cell according to the present invention, the first magnetic memory cell performs all of data writing, data erasing and data reading by electrical signals, so that they can be performed at a very higher speed compared with conventional magnetic memory.

The local heating circuit is used for the data writing and the data erasing, and a high margin can be obtained by applying external magnetic field, thus decreasing error. Data writing and data erasing may adopt any one of the following methods: a magnetic field modulation method in which external magnetic field is changed; and a power generation method in which heat input is changed. In the case where the data writing and data erasing is performed by changing the heat input, there is nothing wrong in using constant magnetic field as the external magnetic field, and a permanent magnet can be used. Note that the external magnetic field may not be applied.

In addition, by providing an auxiliary layer such as a switched connection multilayered film and a magnetic static connection multilayered film in the recording medium made composed of the magnetic thin film, the data writing and the data erasing can be performed with a high margin.

Any magnetic resistor element may be used as long as it changes its resistance value depending on an intensity and direction of magnetic field. When a semiconductor material such as InSb is used, larger resistibility change can be obtained by utilizing so called a shape effect in addition to an increase in resistibility owing to a magnetic resistance effect. Furthermore, NiFe rare earth group-chalcogenide compounds, $CdCr_2S_4$, $CdCr_2Se_4$ and the like show large magnetic resistance effect. Furthermore, also artificial lattice multilayered films such as Co/Au/Co, Fe/Cr/Fe, Co/Cr/Co show a large magnetic resistance effect. A magnetic diode and a magnetic transistor can

also be used.

As to the data writing and the data erasing, a laser beam or a magnetic head can be used in addition to the local heat circuit. On the contrary, in the case of data reading, detection of a Kerr rotation angle by use of a laser beam reflection and data reading by use of a magnetic head can be adopted.

In stead of the magnetic resistor element constituting the data reading circuit, a Hall element or an inductance element having a soft magnetic body as a core can be used. Although the magnetic resistor element and the Hall element can obtain a predetermined output in a DC or pulse driving, the inductance element needs to be AC-driven. An AC-input can be modulated by a single and a plurality of pulses. By connecting a capacitor to the inductance element in parallel or in series, an output can also be obtained by use of resonance. Furthermore, by constituting a bridge circuit by use of the magnetic resistor element, the Hall element or the inductance element, a signal detection sensitivity can be improved.

A second magnetic memory cell of the present invention comprises: a magnetic thin film in which a magnetization easy axis has a film plane vertical direction component; a magnetic field generating circuit for applying local magnetic field to the magnetic thin film to change information of the magnetic thin film; and a reading circuit for reading out the information from the magnetic thin film, the reading circuit being composed of a Hall element disposed close to the magnetic thin film so as to be magnetically coupled thereto and a transfer gate connected to the Hall element in series.

Also in the second magnetic memory cell of the present invention, as in the case of the first magnetic memory cell of the present invention, since the data writing and the data erasing can be performed by electrical signals without mechanical operations, the data writing and the data erasing are performed at a very high speed. The first and second inventions are different in a data writing and erasing method. The data writing and the data erasing in the second invention are performed by a magnetic field generating circuit disposed in the memory cell. The magnetic field generating circuit can be configured to generate magnetic field by, for example, a current flowing through a conductive wire. In this case, large magnetic field can be obtained by forming a coil. Furthermore, by using a superconductor as the conductive wire, generation of further higher

magnetic field is possible. Besides this constitution of the magnetic field generating circuit, the one utilizing an electric magnetic effect in which magnetization in proportion to electric field applied to a magnetic body appears is conceived, as well as the one which is combined with a piezoelectric element and which utilizes a piezomagnetic effect in which magnetization appears in proportion to a stress exerted on a magnetic body.

The magnetic thin film constituting the recording layer can be replaced with individual micro magnets magnetically coupled with a Hall element. In this case, the micro magnet acts as a bias magnet for the Hall element, and a polarity of a Hall element output changes depending on whether the magnetization is plus or minus. Accordingly, a signal detection sensitivity can be improved. By making an aspect ratio of the micro magnet, the micro magnet can increase a generated magnetic field.

Furthermore, in stead of the Hall element constituting the data reading circuit, an inductance element having a soft magnetic body as a core can be used. Although the Hall element can obtain a predetermined output by a DC or pulse driving, the inductance element needs to be AC-driven. An AC-input can be modulated by a single and a plurality of pulses. By connecting a capacitor to the inductance element in parallel or in series, an output can also be obtained by use of resonance. Furthermore, by constituting a bridge circuit by use of the Hall element or the inductance element, a signal detection sensitivity can be improved.

A third magnetic memory cell of the present invention comprises: a memory cell element in which two magnetic bodies are tunnel-connected via an insulator layer; a transfer gate connected to the tunnel coupling element in series; and a magnetic field generating circuit closed to at least one magnetic body so as to be capable of being coupled magnetically thereto.

Also in the magnetic memory cell of the third invention, as in the case of the first and second magnetic memory cells of the present invention, since the data writing and the data erasing do not require mechanical operations and can be performed by electrical signals, the data writing and the data erasing are performed at a very high speed.

The tunnel connection element used in the data reading circuit is obtained by connecting two magnetic bodies via an insulating thin film. Since the magnetic body plays a role as a recording medium, the magnetic body should be a micro magnet in order to stably store the data.

In third invention, the data writing and the data erasing are performed by a magnetic field generating circuit disposed in the memory cell. The magnetic field generating circuit can be configured to generate magnetic field by, for example, a current flowing through a conductive wire. In this case, large magnetic field can be obtained by forming a coil. As the constitution of the magnetic field generating circuit, the one utilizing an electric magnetic effect in which magnetization in proportion to electric field applied to a magnetic body appears is conceived, as well as the one which is combined with a piezoelectric element and which utilizes a piezomagnetic effect in which magnetization appears in proportion to a stress exerted on a magnetic body.

The fourth invention is a hard magnetic thin film which has M (M: one or more of Ti, Zr, and Hf) of 6 to 15 % in terms of atomic fraction, the residual portion is substantially formed of one or more of Fe, Co and Ni and, a magnetization easy axis has a film plane vertical direction component.

The reason why a ratio of the elements constituting the hard magnetic thin film is limited is as follows. If M is set to three atomic fraction or less, coercive force is lowered, and it is difficult to stably store the data when the hard magnetic thin film is used as a recording medium. On the other hand, if M exceeds 50 atomic fraction, a magnetic flux density is significantly decreased, and magnetic property deterioration is brought about. Particularly, when the hard magnetic thin film is used as the recording medium, the content ratio of M should be set within a range from 8 to 30 atomic fraction from the viewpoint of the coercive force and the magnetic flux density.

From the viewpoint of an improvement of the coercive force, a part of M may be substituted with Nb, Mo, Ta, W, and rare earth group elements such as Sm and Er, and a part of T(one of Fe, Co, and Ni or more) may be substituted with V, Cr, Mn, Cu, Zn, Al, Ga, C, B, Si, P, Ge, In, Sn, Sb, Pb, Bi, Pd, Ag, Pt and Au. An amount of the substitution of these elements should be set to several atomic fraction or less.

The magnetic thin film can be generally prepared by a thin film manufacturing method such as sputtering. Furthermore, the magnetic thin film can be prepared as an artificial lattice multilayered film by a method such as MBE. In order to improve the coercive force, annealing should be performed at 400 to 1000 ℃ for one to ten hours after film formation.

(Operation)

As described above in detail, according to the present invention, since all of the data writing, the data erasing and the data reading are performed by electrical signals without mechanical operations, a solid state magnetic memory cell, which can write, erase and read out the data with a high speed, and which can store the data for a long time by utilizing the nature of the magnetic body, and a hard magnetic thin film excellent in corrosion resistance can be provided.

(Embodiment)

Embodiments of the present invention will be described with reference to the accompanying drawings below.

Fig. 1 is a conceptional constitution view according to a first embodiment of the present invention, which belongs to a first invention of the present invention. Reference numeral 10 denotes a heat generation element, and reference numeral 12 denotes a magnetic resistor element. Reference numeral 14 denotes a transistor for supplying/cutting off a current for the heat generation element, and reference numeral 16 denotes a transfer gate. Furthermore, reference numeral 18 denotes a magnetic thin film, which is coupled to the magnetic resistor element 12 magnetically and to the heat generation element 10 thermally.

Current is supplied to the heat generation element by lead wires 20 and 22, and current is supplied to the magnetic resistor element by lead wires 24 and 26. The lead wires 28 and 30 are signal lines of switching transistors 14 and 16, respectively. One of the lead wires 20 and 22 and one of the lead wires 24 and 26 can be shared as an earth line, and other two lines can be shared by making them equal in voltage.

The magnetic thin film 18 is magnetized uniformly in a direction perpendicular to its film plane as an initial state. Binary data (0, 1) is recorded in the memory cell shown in Fig. 1. When the data is written, a signal is input to the lead wire 28, and the switching transistor 14 is rendered to be turned on. Thus, a temperature of a part of the magnetic thin film 18 contacting with the heat generation element increases, and coercive force and magnetic anisotropy of the heated part of the magnetic thin film decrease. Flux reversal of this part occurs by an action of anti-magnetic field from a magnetic thin film adjacent thereto. Furthermore, the data erasing is performed in a similar manner to the above,

and a write mode or an erase mode is chosen by controlling a heat input and a heat input time. The thermal input is performed by controlling a current to the heat generation element, and the heat input time is performed by controlling a pulse width of current pulses to the heat generation element. A method of controlling the write mode and the erase mode differs depending on conditions including sorts of the magnetic thin film. In rare earth group-transition metal magnetic thin film, the writing can be performed by a long pulse heat input, and the erase can be performed by a short pulse heat input. The above described method is so called a power modulation method, and a magnetic modulation method may be adopted, in which controlling both modes are controlled by making the heat input and the heat input time constant and by changing external application magnetic fields during writing and erasing. Alternatively, combined use of both methods is possible. Furthermore, by applying bias magnetic field with a constant intensity, a high margin of the writing and the erase is obtained.

Note that the magnetic thin film 18 should be formed in common to the respective memory cells. Because the anti-magnetic field from the adjacent memory cell must be used during the data writing and the data erasing.

When the data is written in the above described manner and the magnetic thin film has a reverse magnetic domain, a magnetic field intensity H of the center of the magnetic domain just below the thin film or just above is given by the equation: $H = 2\pi Mh/\sqrt{(R^2 + h^2)}$ assuming that a magnetic domain radius be R, a film thickness be h, and a magnetic flux density of the magnetic thin film be $4\pi M$. The larger the magnetic flux density is, and the smaller a relative value of the magnetic domain to the film thickness is, large magnetic field can be generated. Moreover, if the reverse magnetic domain of the magnetic thin film is erased, the generated magnetic field becomes zero. Note that the data writing and the data erasing with a high margin can be performed by using a switched connection multilayered film and a static magnetic connection multilayered film as the magnetic thin film 18.

Furthermore, when the written data is read out, the transfer gate 16 is rendered to be turned on, and a resistance value between the lead wires 24 and 26 or a value of a current flowing through the lead wires may be read out. If the data is written and reverse magnetic field is formed in the magnetic

thin film 18 in response thereto, magnetic field is generated by the reverse magnetic domain. Furthermore, if the data is erased and the reverse magnetic domain does not exist, the magnetic field becomes zero. The resistibility of the magnetic resistor element differs depending on the magnitude of the magnetic field generated in such manner, and the contents of the data can be known based on the magnitude of the magnetic field. The case where the reverse magnetic field exists can be corresponded to 1 of binary data, and the case where the reverse magnetic field does not exist can be corresponded to 0 thereof. Alternatively the case where the reverse magnetic field exists may be corresponded to 0 of the binary data, and the case where the reverse magnetic field does not exist may be corresponded to 1 thereof.

According to the constitution of this embodiment, although the data writing and the data erasing are performed by use of the heat generation by the heat generation element 10, a heat shielding mechanism and heat dissipation mechanism should be provided according to demand. Moreover, by amplifying the output signal, a high sensitivity output can be obtained.

Note that, in order to integrate the memory cells shown in Fig. 1, silicon layers 32 and 34 are evaporated on both planes of the magnetic thin film 18 as shown in Fig. 2, and the transfer gate 16 is formed in the silicon layer 32. The transistor 14 is formed in the silicon layer 34. Then, openings 36 are formed in matrix on the silicon layers 32 and 34, and the heat generation element 10 is formed in the opening 36 of the silicon layer 32. The magnetic resistor element 12 is formed in the opening of the silicon layer 36. Moreover, when terminals are extended from the respective elements and wirings are formed, the integrated magnetic memory of this embodiment is formed.

The thickness of the magnetic thin film 18 is 100 to 1000 Å, and the dimension of one memory element is about 1μm or less. Moreover, in order to make it possible to use the anti-magnetic field from the adjacent memory element for writing and erasing of information, the dimension between the adjacent memory elements must be defined.

Note that the magnetic resistor element 12 may be formed on the heat generation element 10 and the transfer gate 16 and the transistor 14 may be formed in the semiconductor layer 34. In this case, the semiconductor layer 32 is unnecessary.

Fig. 3 is a conceptional constitution view of a memory cell according to a second embodiment of the present invention, which belongs to the first invention of the present invention. Reference numeral 38 denotes a laser, and reference numeral 12 denotes a magnetic resistor element. Reference numeral 16 denotes a transfer gate coupled to the magnetic resistor element in series, and reference numeral 18 denotes a magnetic thin film magnetically coupled to the magnetic resistor element 12. A current is supplied to the magnetic resistor element by lead wires 24 and 26. A lead wire 30 is a signal line of the transfer gate 16.

The magnetic memory cell of this embodiment and the magnetic memory cell of the first embodiment differ in the method of the data writing and the data erasing. The magnetic thin film 18 is uniformly magnetized in a direction perpendicular to its film plane as an initial state. Binary data (0, 1) is recorded in the memory cell shown in Fig. 3. When the data is written, the magnetic thin film 18 is locally heated by the laser 38. Thus, a temperature of the magnetic thin film 18 locally increases, and coercive force and magnetic anisotropy of the heated part decrease. Flux reversal of the heated part occurs by an action of the anti-magnetic field from the adjacent memory cell. Furthermore, also the data erasing is performed simultaneously, and it possible to choose any of a write mode and an erase mode by controlling laser power and laser radiation time. The laser power and the laser radiation time can be controlled by a laser driving system. Furthermore, a laser for the data writing and a laser for the data erasing may be prepared individually. The methods of controlling the write mode and the erase mode differ depending on predetermined conditions such as a sort of the magnetic thin film 18. In the rare earth group-transition metal magnetic thin film, the writing is possible by the long pulse heat input, and the reading out is possible by the short pulse heat input. The above described methods are so called a power modulation method, and the magnetic field modulation method, in which a laser beam having a constant intensity is radiated, and the writing and the reading are performed by changing external magnetic field, may be adopted. Moreover, combined use of both methods is possible. Furthermore, by applying a constant bias magnetic field, a high margin of the writing and the erasing can be obtained.

Furthermore, also by forming the magnetic thin film 18 by a switched connection multilayered film and a static magnetic connection

multilayered film, the data writing and the data erasing are possible with a high margin.

Note that the data reading can be performed in the similar manner to that of the first embodiment.

Fig. 4 is a conceptional constitution view of a memory cell according to a third embodiment of the present invention, which belongs to the first invention of the present invention. Reference numeral 10 denotes a heat generation element, and reference numeral 40 denotes a Hall element. Reference numerals 14 and 16 denote a switching transistor for the heat generation element and a switching transistor for the Hall element, respectively. Moreover, reference numeral 18 denotes magnetic thin film, which is magnetically coupled to the Hall element 40 and is thermally coupled to the heat generation element 10. Lead wires 20 and 22 are power supply lines for the heat generation element, and the lead wires 24 and 26 are power supply lines for the Hall element. Lead wires 28 and 30 are signal lines of the switching transistors 14 and 16, respectively. One of the lead wires 20 and 22 and one of the lead wires 24 and 26 can be shared as an earth line, and other two lead wires can be shared by making them equal in voltage. Moreover, lead wires 42 and 44 are recorded information signal lines.

The data writing and the data erasing in this embodiment are the same as those of the first embodiment.

When the written data is read out, the transfer gate 16 is rendered to be turned on, and an output voltage of the Hall element 40 may be read out by the lead wires 42 and 44. If the data is written and an reverse magnetic field is formed in the magnetic thin film 18 in response to the writing of the data, magnetic field is produced by the reverse magnetic field. If the data is erased and the reverse magnetic filed does not exist, the magnetic field becomes zero. Accordingly, an output of the Hall element 40 differs. Contents of the data can be known based on the magnitude of the output. The case where the reverse magnetic field exists can be corresponded to 1 of binary data, and the case where the reverse magnetic field does not exist can be corresponded to 0 thereof. Alternatively the case where the reverse magnetic field exists may be corresponded to 0 of the binary data, and the case where the reverse magnetic field does not exist may be corresponded to 1 thereof. Note that by amplifying the output signal, a high sensitivity

output can be obtained.

In addition to the heating of the magnetic thin film 18 by the heat generation element 10, the magnetic thin film 18 is heated by the laser 38 as in the case of the second embodiment, and it is possible to form and erase the reverse magnetic field. A conceptional constitution view is shown in Fig. 5.

Fig. 6 is a conceptional constitution view of a memory cell according to a fourth embodiment of the present invention, which belongs to the first invention of the present invention. Reference numeral 10 denotes a heat generation element, and 46 denotes an inductor having a soft magnetic body 48 as a core. Reference numerals 14 and 16 denote switching transistors in series connected to the heat generation element 10 and the inductor 46, respectively. Furthermore, reference numeral 18 denotes a magnetic thin film, which is thermally connected to the heat generation element 10 and magnetically connected to the inductor 46. Lead wires 20 and 22 are power supply lines for the heat generation element, and lead wires 24 and 26 are power supply lines for the inductor. Lead wires 28 and 30 are signal lines for the switching transistors.

The data writing and the data erasing in this embodiment are the same as those of the first embodiment.

The written data can be read out in the following manner. By rendering the switching transistor 16 to be turned on, an AC voltage is applied to the inductor 46 via the lead wires 24 and 26. A frequency of the AC is made coincident with a ferromagnetic resonance frequency which is determined by generated magnetic field at the time an reverse magnetic domain exists in the magnetic thin film 18, magnetization of a soft magnetic body used as a core of the inductor 46, and its reverse magnetic field coefficient. In the case where a reverse magnetic domain is formed in the magnetic thin film 18, a Q value of the inductor 46 becomes zero. When the magnetic field is not formed, the Q value of the inductor 46 becomes unequal to zero. Accordingly, by taking out this difference as an output, content of the written data can be known.

The data reading can also be performed by use of a resonance circuit as shown in Fig. 7 or Fig. 8. In this case, the following fact is utilized. Specifically, since a magnetic field intensity differs in response to the presence of the reverse magnetic field of the magnetic domain of the magnetic thin film 18, μ of the soft magnetic body 48 which is a core of the

inductor 46 varies, and the inductance varies accompanied with the variation of μ. The AC frequency applied may be made coincident with the resonance frequency corresponding to the inductance at the time the reverse magnetic domain exists, or alternatively may be made coincident with the resonance frequency corresponding to the inductance at the time the reverse magnetic domain does not exist. When a series resonance circuit is used, a DC resistor 50 for preventing excess current may be additionally provided as shown in Fig. 9.

Fig. 10 shows a constitutional example of the inductor 46. By arranging the soft magnetic body 48 and a half-turn conductor 52 as shown in Fig. 10, it is possible to form a microinductor simply.

Furthermore, as shown in Fig. 11, as the writing and erasing means, a laser can be used in stead of the heat generation element.

Fig. 12 is a conceptional constitution view of a memory cell according to a fifth embodiment of the present invention, which belongs to a second invention of the present invention. Reference numeral 54 denotes a local magnetic field generation element, and reference numeral 40 denotes a Hall element. Reference numeral 14 denotes a switching transistor in series connected to the magnet field generation element 54, and reference numeral 16 denotes a switching transistor in series connected to the Hall element 40. Reference numeral 18 denotes a magnetic thin film, which is magnetically coupled to the magnetic field generation element 54 and the Hall element 40. Lead wires 20 and 22 denotes power supply lines for the magnetic field generation element, and lead wires 24 and 26 denotes power supply lines for the Hall element. One of the lead wires 20 and 22 and one of the lead wires 24 and 26 can be shared as one earth line. Furthermore, the lead wires 42 and 44 denotes recorded information signal lines for an output.

The magnetic thin film 18 is uniformly magnetized in a direction perpendicular to its film plane as an initial state. In the memory cell shown in Fig. 12, binary data (0, 1) is recorded.

When the data is written, a signal is input onto the lead wire 28, and the switching transistor 28 is rendered to be turned on. Thus, reverse magnetic domain is generated in the magnetic thin film 18 due to reverse magnetic field generated by the local magnetic field generation element 54. Furthermore, the data erasing is performed by reversing the polarity of the local magnetic field generation element 54 and by applying magnetic field in

a direction inverse to that during the data writing. According to this embodiment, since the local magnetic field generation element 54 generates the reverse magnetic field, it is unnecessary to perform the data writing and the data erasing by utilizing the reverse magnetic field from the adjacent memory cell. Accordingly, the magnetic thin film 18 needs not to be sharable for each memory cell, and each memory cell may be independently formed, that is, separately formed.

By using a coil as the local magnetic field generation element 54, large magnetic field can be generated. By using a plain coil as the local magnetic field generation element 54, a micro magnetic field generation element can be formed.

Furthermore, by using a super conductive line for a system including the local magnetic field generation element 54, it is possible to generate large magnetic field. For example, when a one-turn coil as shown in Fig. 13 is formed, a generated magnetic field is 1.5 kOe assuming that $a \gg Z$, $a = 1\ \mu m$, and $I = 300$ mA are established. By increasing the turn number of the coil, it is possible to generate further larger magnetic field. For example, when a section area of the coil is set to 0.1 μm^2, the current density is $3 \times 10^9 A/cm^2$ when $I = 300$ mA is established. Since 10^{10} A/cm^2 is obtained as a critical current density of the NbCN superconductor, the generation of the magnetic field is fully possible. Furthermore, by optimizing the turn number of the coil and a magnetic property of the magnetic thin film, it is not always necessary to use the superconductor line.

Fig. 14 is a conceptional constitution view of a memory cell according to a six embodiment of the present invention, which belongs to the second invention of the present invention. Reference numeral 54 denotes a local magnetic field generation element , and reference numeral 46 denotes an inductor having the soft magnetic body 48 as a core. Reference numerals 14 and 16 denote switching transistors in series connected to the local magnetic field generation element 54 and the inductor 46, respectively. Reference numeral 18 denotes a magnetic thin film, which is magnetically coupled to the local magnetic field generation element 54 and the inductor 46. Lead wires 20 and 22 denotes power supply lines for the local magnetic field generation element, and lead wires 24 and 26 denote signal lines for the inductor. Lead wires 28 and 30 denote signal lines for the switching transistor.

Methods of the data writing and the data erasing in this embodiment can be performed as in the case of the fifth embodiment, and the data reading can be performed as in the case of the fourth embodiment.

Fig. 15 is a conceptional constitution view of a memory cell according to a seventh embodiment of the present invention, which belongs to a third invention of the present invention. Reference numerals 60 and 62 denote magnetic bodies, which are tunnel-connected via the insulating layer 64. Reference numeral 66 denotes a magnetic field generation coil, and reference numerals 68 and 70 denote switching transistors which are respectively connected to the tunnel connection magnetic element 72 and the magnetic field generation coil 66 in series. Lead wires 74 and 76 denote recorded information reading lines, and lead wires 78 and 80 denote information recording/erasing lines. Moreover, lead wires 82 and 84 denote signal lines for the switching transistor.

The tunnel connection element 72 in which the magnetic bodies 60 and 62 are tunnel-connected via the insulating layer 64 has different conductances depending on a relative relationship of magnetic polarization between the magnetic bodies 60 and 62. Specifically, assuming that a state density in the vicinity of a Fermi surface of an up spin band of the magnetic body 60 be D_{11} (K_F), a state density of a down spin band be D_{11} (K_F), and state densities in the vicinity of a Fermi surface of the up spin band and the down spin band of the magnetic body 62 be D_{21} (K_F) and D_{21} (K_F), if the insulating film 64 is fully thin, and if the spin is reserved, when the magnetic polarizations of the magnetic bodies 60 and 62 are parallel, the conductance G_{para} thereof is expressed as follows.

$$G_{para} \propto (D_{11} (K_F)\, D_{21} (K_F) + D_{11} (K_F)\, D_{21} (K_F))$$

when the magnetic polarization of the magnetic bodies 60 and 62 are antiparallel, the conductance G_{anti} thereof is expressed as follows.

$$G_{anti} \propto (D_{11} (K_F)\, D_{21} (K_F) + D_{11} (K_F)\, D_{21} (K_F))$$

Since the equation expressed by $G_{para} - G_{anti} \propto (D_{11} (K_F) - D_{11} (K_F)) \times (D_{21} (K_F) - D_{21} (K_F))$ is established, as the difference of the state densities between the up spin band and the down spin band in the vicinity of Fermi surface becomes larger, large conductance can be obtained.

When the data is written onto the memory cell of this embodiment, the data writing is performed in the following manner. For example, assuming that the case where the magnetizations of the magnetic bodies 60

and 62 constituting the above described tunnel connection element 72 are parallel be an initial state, and the case where the magnetizations of the magnetic bodies 60 and 62 constituting the above described tunnel connection element 72 are antiparallel be a data written state, this assumption is made to correspond to 0, 1 of binary data. This correspondence may be inverted. By conducting the switching transistor 70 to the tunnel connection element 72 in the initial state, the coil 66 inverses the magnetization of the magnetic body 62 by the magnetic field generated by the coil 66. Moreover, when the data is erased, the magnetic field in the inverse direction is generated by the coil 66, and the magnetization of the magnetic body 62 is inversed again, and the magnetization may be restored to the initial state.

Moreover, by using a superconductor line for the magnetic field generation circuit including coil 66, it is possible to generate large magnetic field. By forming a micro magnet by use of the permanent magnet material for the magnetic bodies 60 and 62, the written data can be very stably stored. Fig. 16 shows a constitutional example of the tunnel connection element 72 and the magnetic field generation element 66. The tunnel connection element 72 is constituted by the magnetic bodies 60 and 62 and the insulating body 64, and the soft magnetic body 86 and the magnetic body 62 are magnetically coupled. Moreover, the soft magnetic body 86 is magnetized by a current flowing through a half-turn conductor 88, and a magnetic field is applied to the magnetic body 62. For example, with such constitution, the memory cell is made to be planar and compact-sized.

Next, when the written data is read out, the switching transistor 68 is rendered to be turned on, and a current is supplied to the tunnel connection element 72. Since the conductance differs depending on whether the magnetizations of the magnetic bodies 60 and 62 are in a parallel state or in an antiparallel state, it is possible to know the contents of the data written based on this difference.

Next, the first embodiment of the magnetic thin film used for the above described magnetic memory will be explained.

By use of an alloy target made of Zr having an atomic fraction of 22% and Co which is the substantial residual part thereof, a thin film having a film thickness of 1μm was prepared on a quartz base by an RF sputtering apparatus.

The sputtering conditions at this time were as follows.

RF input: 600 W

Ar gas pressure: 5×10^{-3} torr

Base temperature: 150 ℃

Deposit rate: 0.5 μm/h

The obtained magnetic thin film was subjected to a heat treatment at 700 ℃ for ten minutes in a vacuum, and magnetization procedures in directions perpendicular and parallel to a film plane thereof were examined by use of a high sensitivity VSM. As a result, it was found that the obtained thin film has a magnetization easy axis in a direction perpendicular to its film plane, and a magnetic property that σ (10kOe) = 50 emu/g and Hc = 4.8 kOe.

As described above, since the magnetic thin film having a large coercive force can obtain a sufficient magnetic property even if it is microfabricated as a memory cell, the magnetic thin film is suitable for being integrated. Moreover, since this magnetic thin film does not contain elements which is apt to be oxidized like rare earth elements, this magnetic thin film has an excellent corrosion resistance. Accordingly, this magnetic thin film has a merit that it is easily manufactured and can be used for a long time.

Next, another embodiment of the magnetic thin film will be explained.

A magnetic thin film shown in Table 1 was prepared with a method similar to the first embodiment. A magnetization easy axis of an obtained magnetic thin film was oriented in a direction perpendicular to its film plane. Magnetic properties in the direction perpendicular to the film plane are shown in Table 1.

Table 1

Composition (atom ratio)	σ (10kOe) emu/g	1 Hc (kOe)
$Hf_{16}Co_{78}B_3Si_4$	60	6.0
$Zr_{16}Ti_4Co_{76}B_4$	50	4.1
$Zr_{16}Hf_4Co_{77}B_3$	50	3.9
$Hf_{18}Co_{73}Fe_3B_4$	60	3.1
$Zr_{20}Co_{75}Fe_5$	60	3.4
$Zr_{20}Co_{75}Nl_5$	50	3.0

Since this magnetic thin film also has a large coercive force, the same effects as the above described embodiments can be obtained.

[Effects of the Invention]

As described above in detail, according to the present invention, it is possible to provide a solid state magnetic memory cell capable of performing a high speed data writing, erasing and accessing, and storing the data for a long time. Moreover, it is possible to provide a hard magnetic thin film excellent in corrosion resistance.

4. Brief Description of the Drawings

Fig. 1 is a conceptional constitution view of a magnetic memory cell according to a first embodiment, Fig. 2 is a view showing a state in which magnetic memory cells of the first embodiment are integrated. Fig. 3 is a conceptional constitution view of a magnetic memory cell according to a second embodiment. Fig. 4 is a conceptional constitution view of a magnetic memory cell according to a third embodiment. Fig. 5 is a conceptional constitution view of an embodiment in which data writing and data reading are performed by use of a laser beam. Fig. 6 is a conceptional constitution view of a memory cell according to a fourth embodiment. Fig. 7 shows a parallel resonance circuit used for data reading of the memory cell of the fourth embodiment. Fig. 8 is a series resonance circuit used for data reading of the memory cell of the fourth embodiment. Fig. 9 shows a series resonance circuit for data reading, in which an excess current prevention resistor is additionally provided. Fig. 10 is a constitutional view of a microinductor used as an element in the fourth embodiment. Fig,. 11 is a conceptional constitution view of a memory cell using a laser beam as data writing means and data erasing means in the memory cell of the fourth embodiment. Fig. 12 is a conceptional constitution view of a memory cell according to a fifth embodiment. Fig. 13 is a view showing one turn coil used for computing a magnetic intensity by a magnetic field generation circuit. Fig. 14 is a conceptional constitution view of a memory cell according to a sixth embodiment. Fig. 15 is a conceptional constitution view of a memory cell according to a seventh embodiment. Fig. 16 is a view showing a constitutional example of a tunnel connection element and a magnetic generation circuit in the seventh embodiment.

10......heat generation element, 12.......magnetic resistor

element, 14……switching transistor, 16……transfer gate, 18……magnetic thin film, 20, 22, 24, 26, 28 and 30……..lead wire, 32 and 34……..silicon layer, 36……opening

Agent of Applicant: Attorney Takehiko Suzue

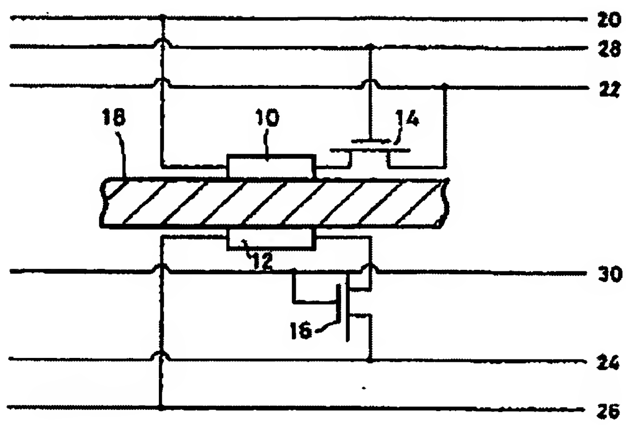

Fig.1

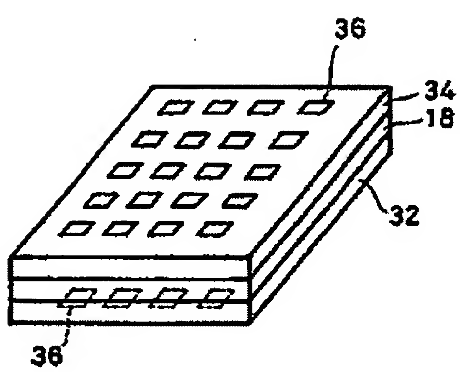

Fig.2

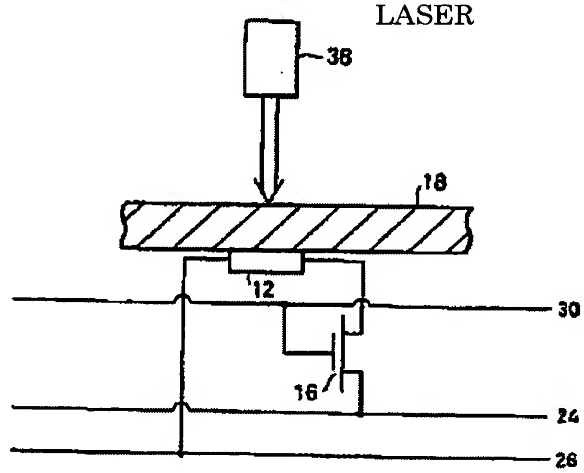

Fig.3

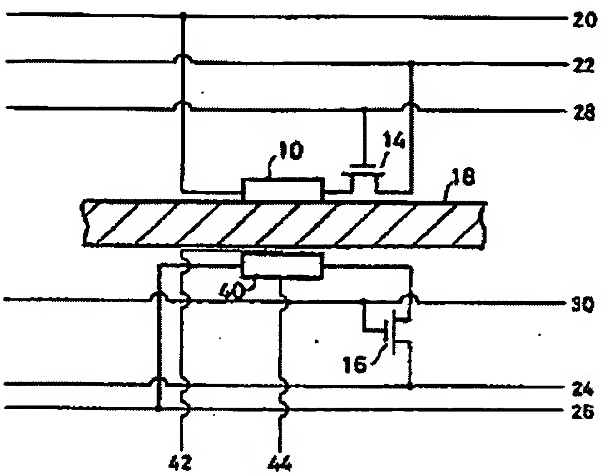

Fig.4

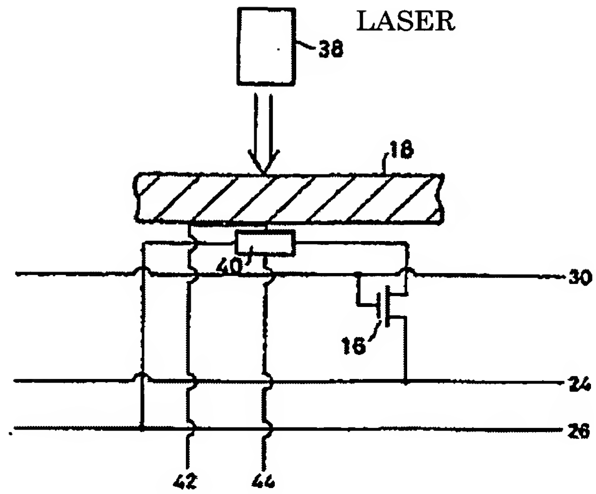

Fig.5

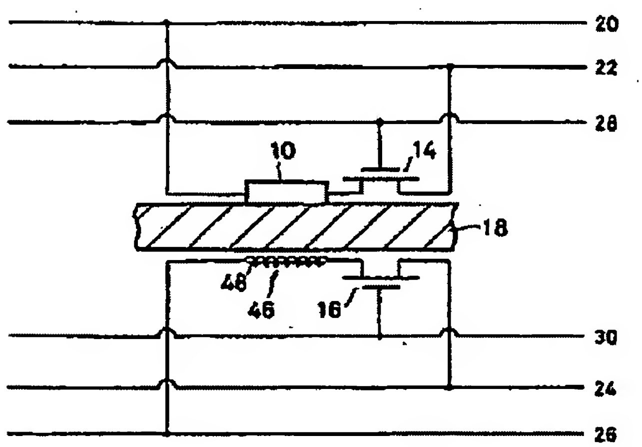

Fig.6

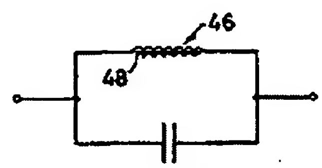

Fig.7

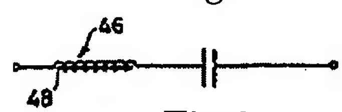

Fig.8

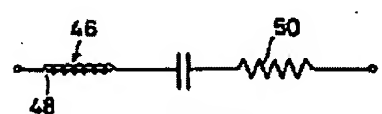

Fig.9

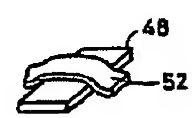

Fig.10

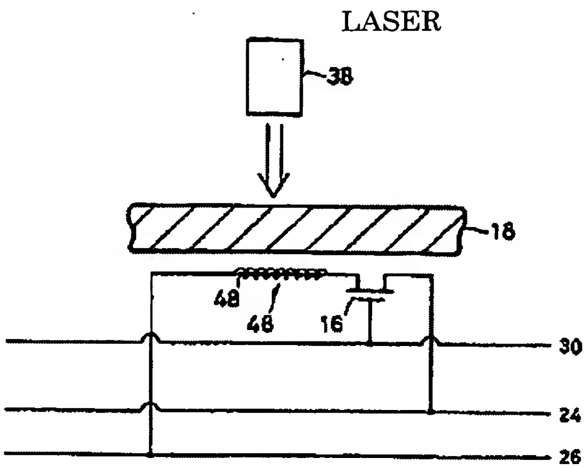

Fig.11

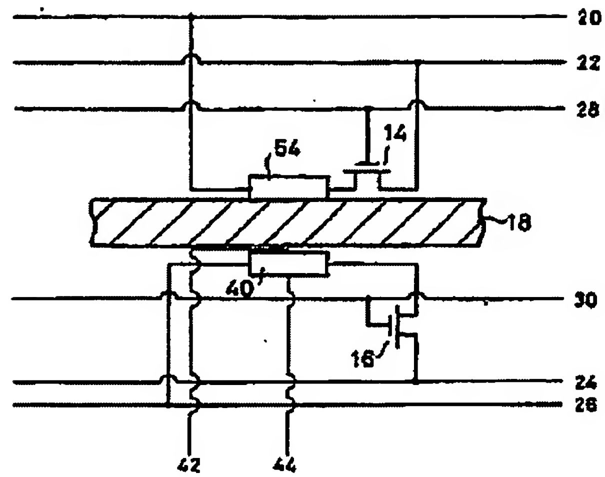

Fig.12

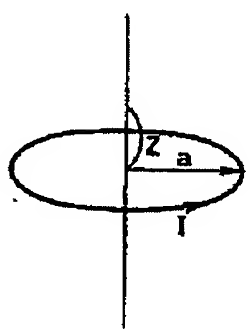

Fig.13

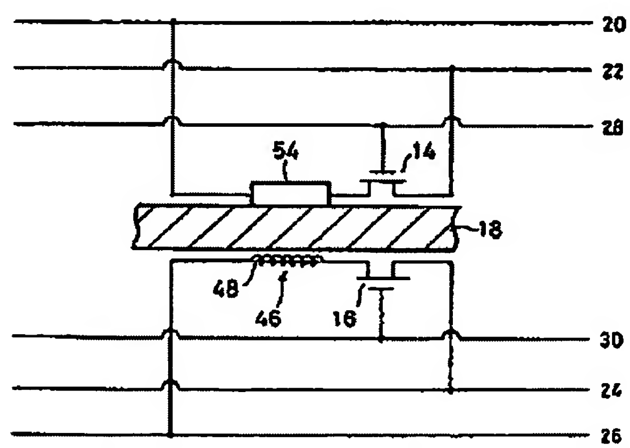

Fig.14

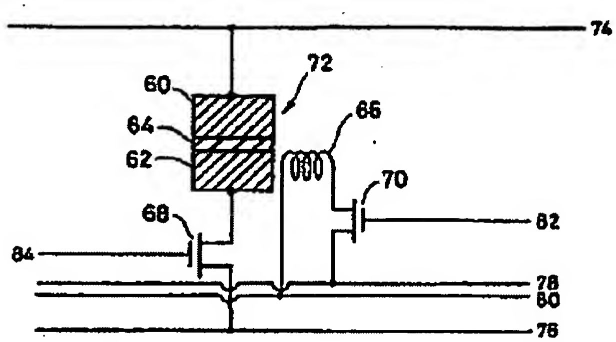

Fig.15

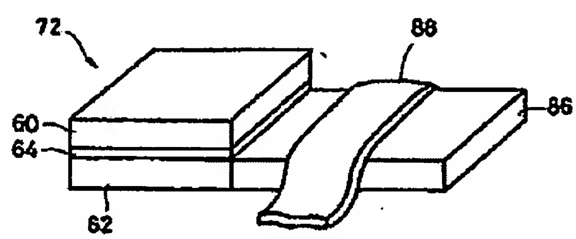

Fig.16